CHAPTER 1

INTRODUCTION

1.1 GENERAL

The premature deterioration of concrete structures in aggressive environment has led to the development of high performance concrete in many fields such as, runway in airport, railway sleepers, nuclear reactor, prestressed concrete bridges, high-rise buildings, offshore platforms, chimneys, and silos etc. In this regard concrete with low permeability (or) higher impermeability is considered as durable concrete. This in turn improves the resistance of concrete against the penetration of harmful substances such as chloride ions, sulphate ions, carbon dioxide, water and oxygen.

1.1.1 Micro Structure of HPC

Concrete is a porous material, which is characterized by the range of pore size and their connectivity is known as porosity. This porosity controls the permeability of concrete, which allows movement of fluid, liable to cause corrosion of reinforcement, expansion and cracking.

The use of mineral admixture (or) finer pozzolan which will fill the space between the cement particles and the aggregate, create dense packing in concrete. This will make concrete more impervious and durable towards hostile environment.
1.1.2 High Performance concrete

It was found that concrete with a very low water/cement ratio or water/binder ratio has improved characteristics such as higher elastic modulus, higher flexural strength, lower permeability, and better durability will be called as HPC.

High performance concrete is essentially a concrete having a low water/binder ratio. A value of about 0.40 is suggested as the boundary between usual concretes and high performance concretes.

Therefore, it is the water/binder ratio which differentiates high performance concrete from usual concrete.

1.1.3 Water / Cement, Water / Cementitious Materials or Water / Binder Ratio

The water/cement ratio concept is a simple and convenient concept as long as concrete does not contain any cementitious materials other than Portland cement.

The use of so called ‘supplementary cementitious materials’ or ‘fillers’ has become more common practice so that many modern concretes now incorporate any one or combination of fillers such as fly ash, slag, natural pozzolan, silica fume, limestone filler, silica filler or rice husk ash etc. These finely derived materials can be called as binders.

Hence it is called water/binder ratio (w/b) instead of the lengthy expression ‘water/cementitious materials ratio’.
1.1.4 Supplementary Cementitious Materials

High performance concrete can be made, using Portland cement alone as a cementitious material. However, a partial substitution of Portland cement by one or combination of supplementary cementitious materials can be advantageous, not only from an economic point of view but also from a rheological and sometimes strength point of view.

Most supplementary cementitious materials have one feature in common: they contain reactive silica which in the presence of water, can combine with lime at room temperature, to form calcium silicate hydrate of the same type as that formed during the hydration of Portland cement. Basically, a pozzolanic reaction can be written in the following manner.

\[ \text{Pozzolan + lime + water} \rightarrow \text{Calcium silicate hydrate} \]

This reaction is generally slow and takes several months for completion at the room temperature. However, the finer pozzolan reaction with lime was faster.

1.1.5 Chemical Admixtures

Sulfonated salts of polycondensate of naphthalene and formaldehyde usually referred to as polynaphthalene sulfonate or more simply as naphthalene superplasticizers.

The best way to evaluate the compatibility between a particular brand of superplasticizer and a particular brand of cement is to study directly the flow characteristics of a particular grout, mortar or concrete in relation to the cement and superplasticizer.
1.1.6 Structural use of HPC

In order to reduce creep and shrinkage, increase the use of high performance concrete in high rise construction will be right solution. As a result, deflections of concrete members are reduced. Whenever high performance concrete is used for columns in high rise buildings, the lateral stiffness of the building is increased, thus reducing lateral sway caused by wind loading. In addition to producing more slender structures, the use of high performance concrete in high rise construction can also decrease the amount of steel and thus the dead load.

1.1.7 Porosity

The main factors affecting the porosity of the hydrated cement paste are the ratio of the volume of water available, the volume of the silicate paste to be hydrated and the amount of air entrapped during mixing. This was recognized as early as 1892 by Feret who formulated his famous expression:

\[
f'_c = k \left( \frac{C_v}{C_v + W_v + a_v} \right)^2 \quad (1.1)
\]

where \( f'_c \) is the compressive strength of the hydrated cement paste, ‘\( C_v \)’, ‘\( W_v \)’ and ‘\( a_v \)’ are the volumes of cement, water and air respectively and ‘\( k \)’ is a constant depending on the type of cement.

Feret’s expression can be rewritten if both the numerator and denominator are divided by ‘\( C_v \)’ as:

\[
f'_c = k \left( \frac{1}{1 + \left( \frac{W_v}{C_v} \right)^{1/2} \left( \frac{a_v}{C_v} \right)^{1/2}} \right) \quad (1.2)
\]
As in hydrated cement paste or concrete, the volume of entrapped air is usually less than 1 or 2% of the total volume of concrete, so the term ‘a_v/C_v’ can be neglected. Therefore Feret’s expression can be written as

\[ f'_c = k \left( \frac{1}{1 + \frac{W_v}{C_v}} \right)^2 \]  

(1.3)

It is clear that in order to increase the compressive strength, the water/cement ratio must be reduced.

1.1.8 The Durability of high Performance Concrete

The durability of concrete is usually the resistance of concrete against the attack of physical or chemical aggressive agents. High performance concrete can be physically or mechanically attacked when exposed to abrasion or freezing and thawing cycles. It can be chemically attacked directly by chloride ions or by sulfate ions, or by acidic or other types of aggressive chemicals. It can also be chemically attacked by a gas such as carbondioxide.

When concrete is subjected to external chemical attack, there is only one way to reduce this external aggression is to lower the porosity and the permeability of the concrete in order to reduce the penetration of the aggressive agents. Therefore to offer the best resistance to external chemical attack, it is necessary that the concrete be as compacted well and impervious. To achieve this, it is necessary that the concrete has a low water/cement ratio, or a low water/binder ratio. In fact it is the water/binder ratio and not the compressive strength that has always been the key factor controlling the impermeability of a concrete and therefore its durability.
1.2 TRANSPORT OF FLUIDS IN CONCRETE

There are three fluids principally relevant to durability of concrete which are: i) water ii) aggressive ions and iii) carbon dioxide and oxygen. They can move through the concrete in different ways, but all movement depends primarily on the structure of the hydrated cement paste and the characteristic of flowing liquid such as viscosity, density and surface tension. Durability of concrete largely depends on the ease with which fluids, both liquids and gases, can enter into, and move through the concrete. This is commonly referred to as permeability of concrete.

Permeability is expressed as the volume of liquid, per unit area of surface per unit time, flowing through a porous material under a constant pressure head and at a constant temperature. The flow is assumed to be one dimensional. The SI unit for the coefficient of water permeability are m$^3$/ (m$^2$/s) = m/s. The permeability coefficient of concrete usually varies between 10$^{-16}$ to 10$^{-10}$ m/s.

1.2.1 Water permeability

The coefficient of permeability is a material characteristic describing the permeation of gases or liquids through a porous material due to a pressure head. Among liquids penetrating through concrete, water represents the most important fluid. In contrast to gases, liquid may be considered as incompressible. If the viscosity of the liquid is taken into consideration and laminar flow is assumed. The coefficient of water permeability is given by
\[
K_w = \frac{Ql\eta}{tA_p\Delta p}
\]  
(1.4)

where,

- \(K_w\) = Coefficient of permeability (m
\(^2\))
- \(Q\) = Volume of Liquid flowing (m
\(^3\))
- \(t\) = time (s)
- \(l\) = thickness of penetrated section (m)
- \(A_p\) = Penetrated area (m
\(^2\))
- \(\eta\) = Viscosity (Ns/m
\(^2\))
- \(\Delta p\) = Pressure difference (N/m
\(^2\))

1.2.2 Transport of ions

Transport of ions in concrete, especially chloride ions, plays an important role in the durability of a reinforced concrete structure. Diffusion is adopted as a predominant transport process in the evaluation of the ion transport property. There are many methods reported for evaluating ion diffusion in hardened cement paste, mortar and concrete. They can be classified as steady-state, non-steady-state and electrical methods.

**Steady-State:**

It means there is no change in concentration of chloride ions with time.

**Non-Steady-State:**

When concentration of chloride ions are changing with time, this condition exists.
1.2.3 Electrical Resistivity

The electrical resistivity (or its inverse, conductivity) of concrete is an important component of reinforcing steel corrosion cells, as high resistivity of the electrolyte (in this case concrete) will reduce corrosion current and slow the rate of corrosion. Electrical resistivity is fundamentally related to the permeability of fluids and diffusivity of ions through porous materials such as concrete. Therefore, electrical resistivity also can be used as an indirect measure of the ability of concrete to penetration of chloride salt solution that may cause corrosion of the reinforcing steel.

1.2.4 Mechanisms of chloride Ingress

For the ingress of chlorides into concrete the continuous network of the capillary pore system of the hydrated cement paste, the cement paste aggregate interface porosity, and micro cracks provide the paths along which the transport of ions occurs. Ion transport in concrete is rather complicated process, which includes diffusion, permeation of the salt solution and the capillary absorption of chloride containing liquids. These complications are usually neglected and pure diffusion is adopted as a predominant transport process in the evaluation of the ion transport property in concrete.

1.2.5 Diffusion

Diffusion is the process by which a fluid moves from region of higher concentration to region of lower concentration of the diffusing substance in concrete and its ionic mobility is known as diffusivity.
The rate of transfer of mass through unit area of section, ‘F’ is proportional to the concentration gradient ‘dc / dx’ and the diffusion coefficient ‘D’ (m²/s).

This relation is expressed in Fick’s first law of diffusion as,

\[ F = -D \frac{dc}{dx} \]  \hspace{1cm} (1.5)

where,

\[ D = \text{Diffusion coefficient (m}^2/\text{s)} \]
\[ C = \text{Ion Concentration at the distance ‘}x_1\text{’ (kg/m}^3\text{)} \]
\[ x_1 = \text{Distance (m)} \]

For transient diffusion processes the equation which describes the change of concentration in a unit volume with time is referred to as “Fick’s second law” of diffusion.

\[ \frac{\partial c}{\partial t} = \frac{\partial}{\partial x_1} \left( D \frac{\partial c}{\partial x_1} \right) \]  \hspace{1cm} (1.6)

where, ‘D’ = Constant or a function of consistent variables

If the boundary condition is specified as \( c = c_0 \) and the initial condition is specified as \( c = 0 \),

For \( x > 0, t = 0 \) a solution is given by,

\[ C = C_e \left( 1 - \text{erf} \left( \frac{x_2}{2\sqrt{Dt_1}} \right) \right) \]  \hspace{1cm} (1.7)
where,

\[ x_2 = \text{Penetration depth (m)} \]
\[ t_i = \text{Duration of immersion (s)} \]
\[ C = \text{Ion concentration at the distance ‘}x_1\text{’ (kg/m}^3\text{)} \]
\[ C_0 = \text{ion concentration at the exposed surface (kg/m}^3\text{)} \]
\[ \text{erf} = \text{Error function} \]

where, erf is the error function values of \( \text{erf} \left( \frac{x_2}{2 \sqrt{D t_i}} \right) \) Vs \( \left( \frac{x_2}{2 \sqrt{D t_i}} \right) \) are available either in mathematical tables or may be calculated with the help of a computer. If experimental data of concentration, C versus depth, \( x_1 \) at a time \( t_i \) are known, the diffusion coefficient \( D \) can be determined from the equation above mentioned by successive approximation to give the best fit, e.g. according to the method of least squares.

1.2.6 Migration

Diffusion can be accelerated by an electrical field. This acceleration is called as migration and is governed by the same basic parameter as diffusion, i.e. by the ionic mobility (Diffusivity) \( D \). The general law governing mass transfer in electrolytes is given by the Nerst – planck equation which has three terms.

\[ \text{Flux} = \text{Diffusion} + \text{Migration} + \text{Convection} \]

1.3 MOTIVATION FOR THE PRESENT STUDY

In the recent years due to rapid Industrialization and modernization of cities, the environment turns to be aggressive in nature, which affects the durability of concrete.
For a variety of reasons, there is a general awareness now that designers of structures must evaluate the durability characteristics of the construction materials under consideration as carefully as other aspects, such as mechanical properties and initial cost. First, there is a better appreciation of the socioeconomic implications of durability. Increasingly, repair and replacement costs of structures arising from materials failure have become a substantial portion of the total construction budget.

The escalation in replacement costs of structures and the growing emphasis on the lifecycle cost rather than the first cost are forcing engineers to pay serious attention to durability issues. Next, there is a realization that a close relation exists between durability of materials and ecology. Conservation of natural resources by making the construction materials last longer is therefore an ecological step. Also, the uses of concrete are being extended to increasingly hostile environments.

Under these circumstances, it is warranted to study the durability aspects of high performance concrete by making use of the different supplementary cementitious materials such as fly ash, silica fume and rice husk ash at different combinations.

From the History of HPC it is observed that few studies were reported on ternary blend (ie, replacement of cement by more than one cementitious compound) of HPC, which were made, tested and proved in many parts of the Globe. Earlier report says that the different brands of cement do not perform in the same way when making high performance concrete (Aitcin 1998). Some perform very well in terms of final strength, but very poorly in terms of rheological behaviour. Hence felt the need of an investigation on ternary blend of HPC by using locally available materials.
In this present Investigation, it is decided to produce HPC by using locally available material and study its long term property such as durability aspects through various modes of experiments and results were correlated to address the problem.

1.4 OBJECTIVES OF THE STUDY

The objectives of the present study were set as follows

- To develop the high performance concrete with characteristic compressive strength of 40 MPa and 50MPa with different combinations of supplementary cementitious materials such as fly ash, silica fume and rice husk ash.
- To select a suitable superplasticizer (SP) through flow test.
- To obtain the optimum pozzolanic reaction, pozzolanic activity index test has to be conducted
- To study the mechanical properties such as compressive strength, flexural strength.
- To study the durability characteristics through
  - Water absorption
  - Water permeability
  - Drying shrinkage characteristics
  - Assessment of rapid chloride permeability of concrete mixtures
  - Determination of steady state diffusion co-efficient by Nernst – Einstein equation.
- Determination of non-steady state diffusion co-efficient by modified Tang Luping method.
- Electrical properties such as, DC resistivity.

### 1.5 METHODOLOGY

Experimental Investigation was conducted on High Performance Concrete to study the mechanical and durability characteristics with supplementary cementitious materials such as silica fume, fly ash, and rice husk ash. Compatibility of super plasticizers and mineral admixtures with cement were studied by flow test and optimum dosage of fly ash, silica fume, Rice Husk ash and super plasticizer were found out from the flow test.

The qualities of mineral admixtures were checked by pozzolanic activity index test. Control high performance concrete mixtures were designed with characteristic strength of 40MPa and 50MPa using ACI – 2114R – 93. The optimum percentage of replacement of cement by fly ash, silica fume and rice husk ash were 40% fly ash + 10% silica fume, 50% fly ash + 10% silica fume, 40% fly ash + 10% rice husk ash and 50% fly ash + 10% rice husk ash by mass of cement respectively. The specimens were tested for durability related properties like water permeability, water absorption, mechanical properties like compressive strength (3, 7, 28 and 56 days) and flexural strength.

Chloride penetration and chloride diffusibility in high performance concrete were studied using rapid chloride permeability test and determination of steady state diffusion coefficient by using Nerst – Einstein equation and method proposed by Tang Luping for examination of non steady
state diffusion co-efficient, Shrinkage properties of HPC and the electrical properties such as resistivity of the concrete specimens were studied.

1.6 ORGANIZATION OF THE THESIS

The details of the research work carried out have been reported in six chapters. The importance and practical significance of the problem are dealt in chapter 1. A general introduction on High Performance Concrete and motivation for the present study with methodology are discussed in the same chapter. Chapter 2 presents a brief review of the literature on micro structure, mechanical properties, transport properties, electrical resistivity and drying shrinkage properties of high performance concrete. Material properties of cement, aggregates, water and admixtures with proportions of ingredients are dealt in chapter 3. The detailed experimental investigations on mechanical and durability related properties of high performance concrete are reported in Chapter 4. The detailed discussions on experimental results with graph are reported in chapter 5. Chapter 6 gives the summary of the work and the conclusions derived from the study. The schematic structure of the thesis is shown in figure 1.1.
Chapter 1
Introduction, Motivation and Objectives of the present study

Chapter 2
Review of literature on Durability Studies, Mechanical properties, Transport Properties, Electrical Resistivity and Drying Shrinkage Properties of HPC.

Chapter 3
Material properties of Cement, Aggregate, Water and Admixtures with proportions of ingredients

Chapter 4
Experimental investigation on Mechanical and Durability related properties of High Performance Concrete are reported.

Chapter 5
The detailed discussions on experimental results with graph are reported.

Chapter 6
Summary and Conclusions

Figure 1.1 Schematic Structure of Thesis